The Lowdown on High-Voltage DC Testing

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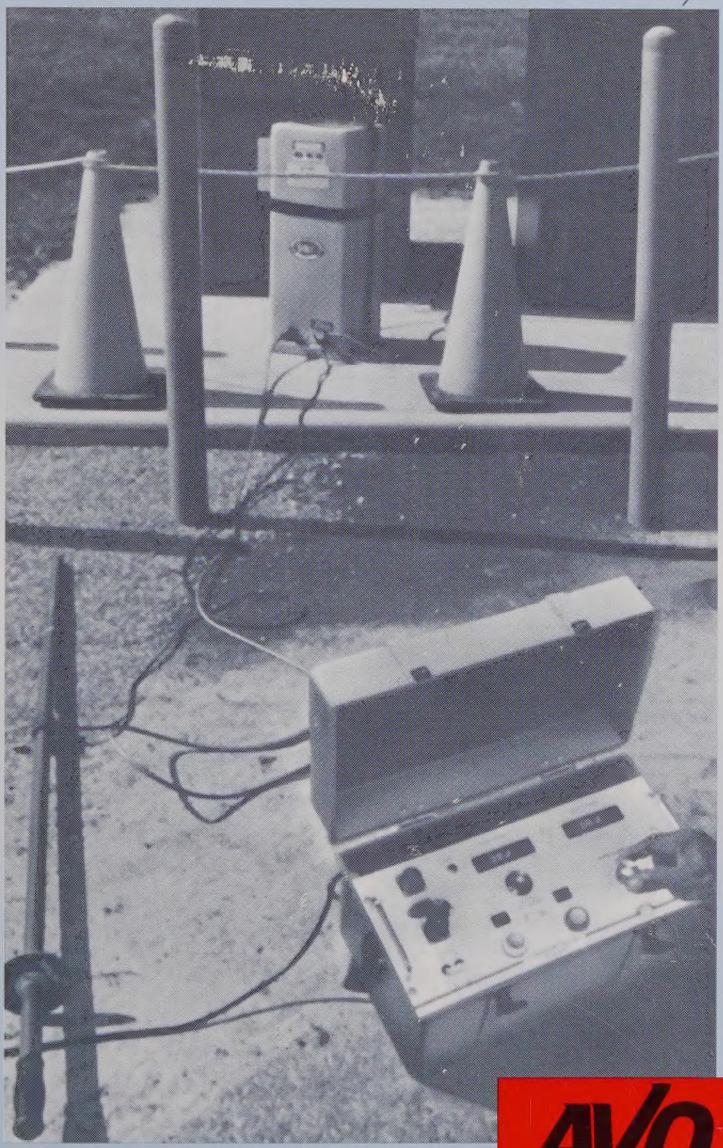

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Revision A
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AVO INTERNATIONAL

The Lowdown On High-Voltage DC Testing

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1

GIVING YOU THE LOWDOWN

In bringing you the lowdown on dc high-voltage insulation testing, we are not attempting to replace the equipment manuals supplied by manufacturers of high-voltage insulation test sets. Our purpose is to provide you with additional useful information about testing procedures that you can use to supplement your instruction manuals.

We begin in Section 2 by discussing the underlying principles on which insulation testing is based. This basic information should help you choose the most appropriate test for your needs.

Pre-test procedures are the same for each test method. To avoid unnecessary repetition, we have provided these instructions separately in Section 3, "Preparing for the Test." When you perform any of the tests, you are asked first to refer to Section 3.

For ease of use, *The Lowdown on High-Voltage Testing* contains step-by-step instructions on the following four test methods:

- Proof Test
- Insulation Resistance Test
- Polarization Index Test
- Step Voltage Test

Although we give you the lowdown on how to perform tests, no one can give you general rules for the interpretation of the results—meaning varies with different types of apparatus. The test data gives you clues to which you must add other information, such as:

- Previous history of the apparatus
- Results of careful visual inspection
- Comparison with other similar apparatus
- Manufacturer's recommendations
- Other specifications that may be relevant, (see Appendix D).

In difficult cases you may need to consult the manufacturer of the equipment under test or a consulting engineer. In most cases, however, the correct course of action becomes obvious after consideration of all the evidence. The courses of action open to you are usually as follows:

- Return the apparatus to service until the next routine maintenance and test.
- Return the apparatus to service but perform repairs or replacement as soon as convenient.

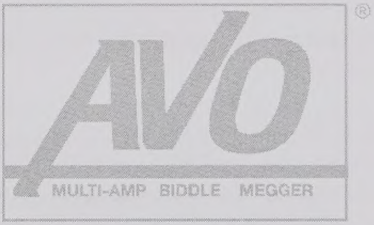
- Repair and/or clean and dry the apparatus and retest.
- Replace the apparatus.

We hope this manual gives you the lowdown on the testing techniques you are most likely to require. Nevertheless, an almost unlimited amount of additional information on high-voltage testing is available to you. We have provided a reference list of sources in Appendix D.

AVO International will be pleased to discuss your requirements for dc high-voltage testing equipment, including test power supplies and partial discharge measurements.

In addition to dc high-voltage test equipment, AVO International has specialized in all forms of insulation testing for many years, going back in some cases to the early days of the twentieth century. We are the supplier of the famous Megger® Insulation Testers for dc insulation testing.

We can also supply equipment for ac high-voltage testing, including test power supplies and power factor and partial discharge measuring systems.



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2

AN INTRODUCTION TO HIGH-VOLTAGE TESTING

The information in this section will help you to decide:

- When to use a direct current high-voltage rather than a medium-voltage test.
- Which of four direct current high-voltage tests is appropriate for your equipment.

To help you make informed decisions, we include the following information:

- A definition of Ohm's Law, the underlying principle on which all insulation resistance measurements are made.
- An explanation of the complex currents that flow when a dc test voltage is applied to the equipment under test.

- Test methods for high capacitance equipment.
- Test methods for low capacitance equipment.
- Testing three-phase apparatus.
- Types of test set metering.
- When to test insulation.

High-Voltage DC Testing versus Medium- Voltage Testing

There are two common methods of testing insulation on high-voltage equipment:

- Direct current high-voltage testing, which measures the current flow through the insulation at 5000 volts and above.
- Medium-voltage testing, which measures the insulation resistance at up to 5000 volts (using a Megger® Insulation Tester).

Dc high-voltage testing is superior to medium-voltage testing because it stresses the insulation at or above the working level. This gives you more information about the condition of the insulation and helps you predict problems before a breakdown occurs. If you use a high-voltage test, you can have more confidence that the apparatus is in suitable condition to remain in service. High-voltage tests are more complicated to perform, so they cost more than medium-voltage tests.

Medium-voltage testing usually tests the insulation at a level below full working voltage. Although it may not detect some problems with the insulation, it is a great deal better than no test at all. Medium-

voltage tests are simple to perform and are less expensive than high-voltage testing.

The choice between high and medium-voltage testing depends on the importance of maintaining the apparatus in service without interruption. If the consequences of a failure in service would not be unduly disruptive or expensive, medium-voltage testing may be sufficient. If you need to keep the equipment in service at all times, high-voltage testing is for you.

Figure 1: Typical medium-voltage Megger® Insulation Testers. The instrument on the left tests up to 5000 Volts with very high megohm sensitivity. The instrument on the right tests up to 1000 Volts.

Ohm's Law and Insulation Resistance

Ohm's Law is used to show the relationship between current, voltage, and resistance, as follows:

$$I = V/R \text{ (or } V = I \times R \text{ ... or } R = V/I)$$

where

I = Current in Amps

V = Voltage in Volts

R = Resistance in Ohms

Sometimes these equations are given with E (EMF) instead of V as the symbol for voltage.

These are general equations that apply to all electrical work.

For insulation resistance measurement, you usually want to calculate the insulation resistance when you already know the current, (from reading the output current on the test set), and the output voltage, (you have set it, using the test set voltmeter).

The current reading is almost certain to be in micro-amps. The micro-amp is a unit of current that equals the current in amps divided by a million. This is quite convenient, because we can now rewrite the equation:

$$\text{Insulation Resistance} = \frac{\text{Voltmeter Reading}}{\text{Current Meter Reading}}$$

where

Insulation resistance is given in Megohms

Voltage is measured in Volts

Current meter reading is given in micro-amps

Megohms are millions of ohms. They are the units most commonly used to measure insulation resistance because you don't have to talk about hundreds and thousands of millions of ohms.

Sometimes you will also encounter the term gigohm, which is one thousand megohms. Gigohm is a useful term for very high resistances.

> ***WHAT IS THE UUT?***
> *For convenience we have used the term "Unit Under Test" or "UUT" to refer to all types of apparatus you might test: cable, switchgear, motor, or what-have-you.*

Time-Dependent Currents and Current Changes in Insulation Testing

With some types of equipment, time-dependent currents cause the meter readings to change over a long period of time, making it impossible to obtain an accurate reading in a reasonable length of time. You can overcome this problem by using a test that does not depend on a single reading. Before we tell you about the tests, you should understand why time-dependent currents occur.

Please refer to Figure 2.

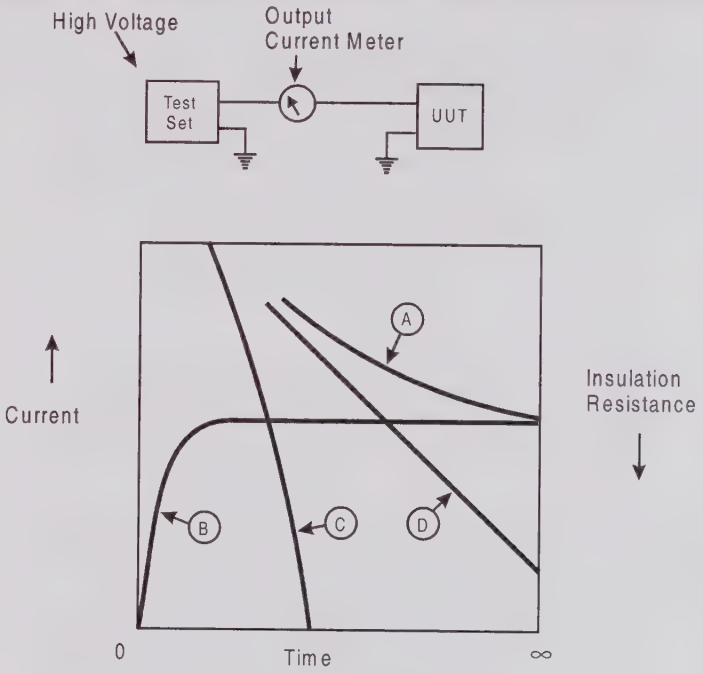

Figure 2: Graph of time-dependent currents when a dc voltage is applied to insulation.

The Total Current (A) is the value you will read on the meter of your test set. The total current is a composite of three currents: the leakage current (B), the capacitive current (C), and the absorption current (D).

The Leakage Current (B) rapidly reaches a constant value and then does not change. THIS IS THE CURRENT YOU WANT TO MEASURE.

The Capacitive Current (C) is caused by the charging of the capacitance of the unit under test . This current decreases to almost zero in a short time.

The Absorption Current (D) is absorbed by the insulation while some changes are taking place in the molecular structure of the material. It lasts for a variable length of time. In some cases it falls to zero in a few seconds, but in other cases it can persist for hours.

When the capacitive current (C) and the absorption current (D) have fallen almost to zero, the total current (A) and the leakage current (B) are the same.

Because you can measure only the total current on the meter, you cannot measure the leakage current until the capacitive current and the absorption current have died down. In other words, you can measure true leakage current only when the meter reading becomes steady.

Time-dependent currents cause problems when you are testing the insulation on equipment with high capacitance. They are not significant on low capacitance equipment. As a result, the testing methods used for high and low capacitance equipment are different. It is essential, therefore, that you know the approximate capacitance of the equipment you are testing.

Capacitance of the UUT

Low Capacitance

High-voltage bus systems, switchgear, and electric cords are examples of low capacitance equipment. If you are testing a low capacitance UUT, the time-dependent capacitive current and absorption current will probably decrease to zero very quickly. In this case, you can measure the true insulation resistance with a simple insulation test because the meter reading will become steady almost immediately.

High Capacitance

Large generators, long lengths of cable, large motors, and similar large apparatus with complex insulation systems are examples of high capacitance equipment. With these kinds of apparatus—especially when they have insulation systems based on paper, rubber, or EPR insulation—the capacitive current will last a long time, and the absorption current may continue for hours. In these cases you will not be able to get a steady meter reading or use a simple insulation resistance test. Instead, we recommend that you use a test that establishes a trend between readings, such as the polarization index test or the step-voltage test.

What To Do When The Capacitance Is Not Known

As with most questions concerning dc high-voltage testing, there is no clear-cut way to know the

capacitance of every type of equipment. Nor is there a simple answer to the question, "What is the dividing line between low and high capacitance?", because the answer depends on both the capacitance of the UUT and the materials in the insulation system of the UUT. The absorption current varies greatly with the type of insulating material.

If you are uncertain about the capacitance of the UUT and its suitability for simple insulation testing, a quick way to find out if a problem exists is to perform a medium voltage, (500 to 5000 volts) insulation test with a Megger® Insulation Tester. If this gives you a steady reading in a minute or less, then time-dependent currents will not be a problem on a high-voltage test. If the medium-voltage test takes much longer than a minute to stabilize, you must either run the insulation resistance test for a relatively long time until the reading is steady, or choose a test such as the polarization index test or the step-voltage test.

SAFETY NOTE

After testing, always leave the UUT short-circuited for 5 to 10 times as long as the test voltage was applied. The absorption current (current (D) in Figure 2) is reversible. The energy absorbed when the current is applied is stored in the dielectric. It will cause a voltage to appear across the UUT after it has been disconnected from the high voltage, even if short-circuited for a time.

Which Test Should I Use?

You may choose between the following four test methods. Each test is described fully in subsequent sections of this manual. Be sure to refer also to safety procedures in Section 3.

The Proof Test

Because the proof test involves no meter reading, it can be used on equipment of any capacitance. The proof test indicates the condition of the insulation under high stress conditions. It tells you what is going on at the moment of the test, but it provides no diagnostic information or data that can be recorded for future use. It is simple and quick to perform. See Section 4 for more information. Be sure to review SAFETY PROCEDURES before performing the test.

The Insulation Resistance Test

The insulation resistance test can be used on equipment with a capacitance low enough to provide a steady insulation reading after a reasonably short test time. If the test voltage is above normal working voltage, the insulation resistance test is similar to the proof test except that it gives a value of resistance to be used for comparison in future testing. See Section 5 for more information. Remember to review SAFETY PROCEDURES before performing the test.

The Polarization Index Test

The polarization index (PI) test is one way to test the insulation on high capacitance equipment because it measures the ratio between two readings taken at a nine-minute interval. These measurements can be made before the time-dependent currents have died down. This test requires care in its application in order to obtain good results.

The readings from a polarization index test are not significant for low capacitance UUT's. Because the time-dependent currents die down almost immediately, both measurements will be the same and the ratio will always be approximately 1.0. See Section 6 for more information and to review SAFETY PROCEDURES.

The Step-Voltage Test

The step-voltage test is the best way to test the insulation on high capacitance equipment. It is similar to the polarization index test but more extensive, because several measurements are taken at regular intervals. These readings are plotted on graph paper to provide a curve of insulation resistance or leakage current measurements. Consequently, the test tends to provide a better record for future comparison. It requires considerable care in its application to obtain good results.

The step-voltage test is not suitable for low capacitance equipment. The time-dependent currents diminish quickly on low capacitance apparatus. Therefore, the readings would be the same at each interval and no curve would be

established. See Section 7 for more information and remember to review SAFETY PROCEDURES.

Testing Three-Phase Apparatus

Throughout this manual, we refer to tests made between the line terminal and ground.

When you are testing three-phase apparatus, you have two choices:

1. You may connect all three line terminals together and treat the UUT as though it is single phase.

2. You may test each phase to ground as three separate tests.

The better of these two choices is to test each phase separately because you can compare the results of each test. For good insulation, all three phases should be similar. The deterioration of insulation at weak points causes the results from each of the three phases to be different. Of course, some types of insulation deterioration (moisture or contamination, for example) may affect all three phases equally, but a wide variation in readings from the three phases is always a cause for concern.

Test Set Metering

Dc high-voltage test sets are equipped with meters to measure the output voltage and current. They may be digital or analog.

The metering of the output current may be calibrated to read current or to read the insulation resistance of the equipment under test. If the meter is calibrated in resistance, it may read directly at only one output voltage. You will then have to apply a correction factor for other voltages. See the instrument's instruction manual for an explanation.

Test sets with meters that read resistance are best used for the insulation resistance test and the polarization index test.

Test sets with meters that read current, such as the Biddle® 70 kV DC Test Set, Cat. No. 220070, should be used for the step-voltage test.

NOTE: You can use any type of metering for the proof test because you do not measure either current or resistance, although you can use a sudden change of reading as one indication that breakdown has occurred.

If you use a test set with current metering for the insulation resistance test, you will have to convert the measurement to resistance, using Ohm's Law.

When Should Insulation be Tested?

You should test the insulation on the equipment soon after installation. This initial acceptance test is usually part of the contract between the supplier and the purchaser.

You should also test the insulation after routine maintenance has been performed on the equipment and before it is re-energized.

If you test routinely and keep records of the results, you can keep track of the condition of the insulation as it deteriorates over time. How frequently you perform these tests will depend on how you balance the importance of having your equipment in service at all times against the costs of running the tests.

3

PREPARING FOR THE TEST

The preliminary procedures described in this section apply to every kind of equipment and any of the various test methods. We recommend that you read and learn the following instructions:

Safety

Anyone using high voltage test equipment must have a healthy respect for all safety rules-don't take chances with your life or the lives of other people.

- Read all safety instructions carefully.

Pre-planning

To ensure good data and compliance with the owner's and the manufacturer's recommendations, in advance of the test you should:

- Calculate phase-to-ground voltage.
- Decide which level of test voltage to use.

- Know which time intervals to allow.

Set-Up Procedures

Keep in mind that the suggestions we give for set-up do not take the place of the manufacturer's testing recommendations. Before you begin any test, refer to the appropriate manual for specific information on the UUT and test set. We provide supplementary instructions on:

- Preparation of the UUT
- Checking the High-Voltage Test Set
- Connecting a Guard Terminal
- Connecting the High-Voltage Test Set to the UUT
- Dealing with Line Transients.

Safety Procedures

WARNING!

Remember that high-voltage contact can cause death or serious injury.

Prepare the Location

- Keep people out of the area in which the test is to be performed.
- Keep people out of the areas at the other end of the energized cables. Remember that remote parts of the system may be energized during the test.

- Erect barriers between the test area and surroundings.
- Display signs in a prominent location, warning of high voltage testing.
- Consult the test equipment manual so that you know the clearance that is safe for the voltage you are using.

De-energize the UUT

- Switch it off and ground it for a time.
- Never approach any high-voltage connection without first applying a safety ground.

Use equipment that is designed for high-voltage testing.

- Never use equipment intended for some other purpose.
- Never use high-voltage test equipment and accessories for any purpose not recommended by the manufacturer.

Be prepared for emergencies

- Always have at least two people present during the test.
- Know in advance what to do in a case of accidental shock.

Follow all safety rules; Company, Union, etc.

- Find out whether any specific company, union or other safety regulations apply to your test.

- Refer to the manual supplied with your test equipment. We also highly recommend that you obtain and read IEEE 510-1983, Recommended Practices for Safety in High-Voltage and High-Power Testing, published by The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street, New York, NY 10017.

Preplanning the Test

Calculating Phase-to-Ground Voltage

When pre-planning the test, you must decide which level of test voltage you are going to use. This means that you must first calculate the phase-to-ground voltage that will stress the insulation during the test.

- Most high-voltage apparatus is designed for three-phase operation, so the name-plate voltage is usually given as the phase-to-phase voltage rating.
- To calculate the phase-to-ground voltage: Find the phase-to-phase voltage (the name-plate voltage) and divide it by the square root of 3, or approximately 1.73.

  Example:
  For a piece of apparatus rated at 15,000 volts phase-to-phase, the normal phase-to-ground voltage would be 15,000/1.73, which equals 8660 volts. This is the alternating current (ac) phase-to-ground voltage.

During direct current (dc) high-voltage insulation tests, the dc voltage for insulation tests must be

higher than the ac phase-to-ground voltage that you have just calculated.

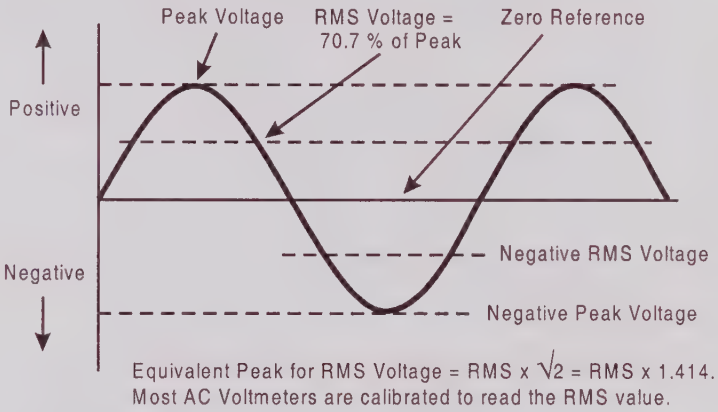
Peak Voltage
RMS Voltage = 70.7 % of Peak
Zero Reference
Positive
Negative
Negative RMS Voltage
Negative Peak Voltage
Equivalent Peak for RMS Voltage = RMS x √2 = RMS x 1.414.
Most AC Voltmeters are calibrated to read the RMS value.

Figure 3: Relationship between Peak and RMS values of ac voltage

The ac voltage rating is almost always specified in terms of its Root Mean Square (RMS) value. The crest or peak value is 1.414 times the RMS value for a sine wave.

The dc voltage used in testing should be based on the *ac peak value* so that it is related to the maximum stress the insulation carries in normal ac operation. In our example above, the RMS phase-to-ground voltage of the 15,000-volt UUT is 8660 volts, but its peak value is 12,246 volts (8660 x 1.41). This is the voltage at which the dc test voltage is equal to the peak ac voltage.

The UUT manufacturer will probably be able to provide you with recommended test voltages and specifications. Alternatively, national standards are

provided by The National Electrical Manufacturers Association, The Institute of Electrical and Electronic Engineers and The Underwriters Laboratories, Inc. See Appendix D for more details.

In most cases, though, it's considered good practice to stress the insulation *above* normal in order to detect incipient weaknesses in the insulation. Stressing above normal also allows for the fact that voltage surges occur on the power line and will be applied to the UUT. You can calculate the above-normal voltage to use by multiplying the normal peak voltage by some agreed-upon multiplier.

Multipliers, which vary with the type of equipment and the age, may range from 1.1 to 2 or higher. One old rule-of-thumb for small, new apparatus is twice the normal stress plus 1000 volts. On older equipment or larger equipment, a lower number is usually used. Some examples are given in various specifications (see Appendix D).

Keep in mind that the normal rating of the power supply is not constant. The power company standards may allow the line to rise 5% to 15% in normal operation.

TEST VOLTAGE LEVEL DETERMINATION

- Find the nameplate phase-to phase voltage.
- Divide it by 1.73, (square root of 3)
- Multiply it by 1.41, (equivalent dc peak voltage)
- Multiply by test voltage multiplier, (typically 1.1 to 2).

Length of Time and Number of Steps for Test Voltages

Having selected the test voltage, you must now decide how long you plan to apply it to the UUT.

Refer to the UUT manual for the manufacturer's recommendations or follow the recommended practice given by national standards. Remember to have a stopwatch handy to time the tests.

The Proof Test

Generally, for proof testing the voltage is held for one minute, although other times are occasionally specified.

Hold the voltage until the reading is steady. Alternatively, wait until the reading exceeds some predetermined value that is considered satisfactory. This second approach saves time but is inferior because it gives no data to use for comparison in the future.

Polarization Index Test

The voltage is usually applied for ten minutes. Readings are taken at 1 minute and 10 minutes.

The Step-Voltage Test

Typically, the steps in a step-voltage test are made at one-minute intervals. It is usual to make five steps. The voltage for each step should be the maximum voltage to be applied divided by the number of steps. For example, if the maximum voltage is 10,000 volts and five steps are used, each step should be 2000 volts.

The time interval used will depend on the capacitance and the insulation system of the UUT. It is best to choose an interval that gives a changing value of insulation resistance for each step. If the interval is too long, the last steps will be constant. Experimentation with a medium-voltage test will help to establish a suitable time interval. One-minute steps are typical for a wide range of UUTs.

IMPORTANT!

Who should agree to the test values? When you have decided on the test voltages and time(s), you should consider whether you may need to obtain approval for your test plan

The owner of the apparatus, the supervisor of the operation that uses the apparatus and perhaps other people have an interest and should be in agreement.

Consult standards, references and the manufacturer's handbook to make sure that you are complying with the manufacturer's recommendations.

Ensure the test set is correctly rated for the test.

Preparing the UUT

Make sure that the circuit path is free from conditions that may distort the data. To do this:

Disconnect all other equipment that may severely distort test data—surge protective devices, transformers, temperature-monitoring transducers and similar devices.

Make sure that terminals, motor windings and all high-voltage connection points are clean and dry. High voltage tracking along moist or dirty paths to ground can distort test data. Make sure there are no sharp edges on terminals, motor windings or any high-voltage connection points. Sharp points cause ionization leakage (corona), which can distort test data. Corona can be eliminated by covering sharp

points with electrical putty or plastic bags (plastic sandwich bags work well). See Appendix C for a discussion of corona.

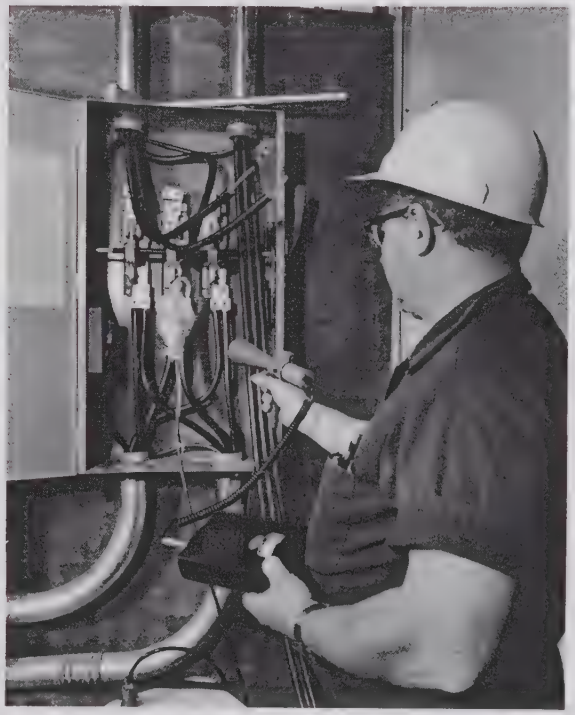

Figure 4: How to prevent ionization at sharp points

WARNING!

If the plastic bag blows up like a balloon, it has become charged and must be discharged to ground with a stick before you touch it.

We recommend that you check the circuit of the UUT with a Megger® Insulation Tester to make sure that the circuit is clear of obstructions and that there are no obvious problems before proceeding with a high- voltage test.

Checking the High-Voltage Test Set

Know and apply all safety procedures. Always remember to ground the output every time before you touch it.

Suspend the end of the high-voltage cable off the ground at a safe distance. Clean nylon cord is useful for this. Turn the set on. Turn the voltage up to the highest value to be used during the test.

The micro-ammeter should read close to zero. If there is a small amount of microampere leakage, you may suppress it by tying a plastic bag over the cable clip or other metal objects that may cause ionization. Eliminate surface leakage by cleaning the insulator surfaces.

Make sure the clearances from the high-voltage terminal to ground are sufficient. Corona (ionization) can cause leakage currents to appear if the output cable is too close to other conducting material, such as barriers or other grounded metal objects. See Appendix C for a further discussion of corona.

Internal leakage in the test set sometimes occurs if condensation has formed inside. Gentle heating and time are the solutions to this problem.

Connecting a Guard Terminal

The purpose of the guard terminal is to eliminate the effect of leakage through paths in parallel with the insulation you want to test. Typically, this may be in the output cable of the test set or over the surface of exposed insulation. The guard intercepts currents caused by these unwanted parallel paths and connects them to ground, bypassing the current or resistance measuring device.

"Cold" Guard Connections

All Biddle® HighVoltage Dielectric Test Sets use a "cold" guard connection. Here the guard terminal is connected through the test set to ground by a comparatively low impedance, and the guard terminal is at almost ground potential.

- The ground and the guard terminal must be spaced the same distance from the high-voltage terminal to avoid flashover.

"Hot" Guard Connections

Older Megger® Insulation Testers and some other testing devices use a "hot" guard connection. In this case, the guard connection is at almost the same potential as the high-voltage cable terminal. With the guard at almost the same potential as the test voltage, no current will flow into the guarded parallel path.

- "Hot" guard terminals (close to high voltage) must be spaced the same distance from

ground as the high-voltage cable terminal to avoid flashover to ground.

- "Hot" guards are not often found on high-voltage test apparatus.

Connecting the High-Voltage Test Set to the UUT

Refer to the instruction manuals for your test set and the UUT for detailed information.

Make sure that the test set case and UUT case are properly grounded. This protects the operator and the test set from high voltage surges if there is a breakdown from the high voltage to ground.

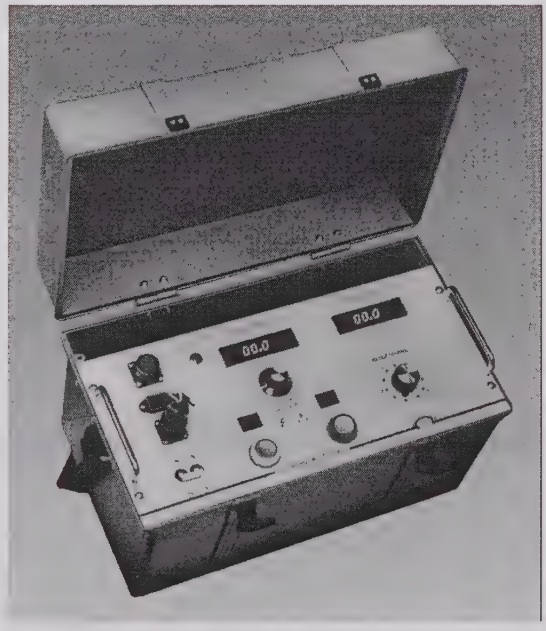

Figure 5: Control Unit of 70 kV, 120 kV or 160 kV dc test set

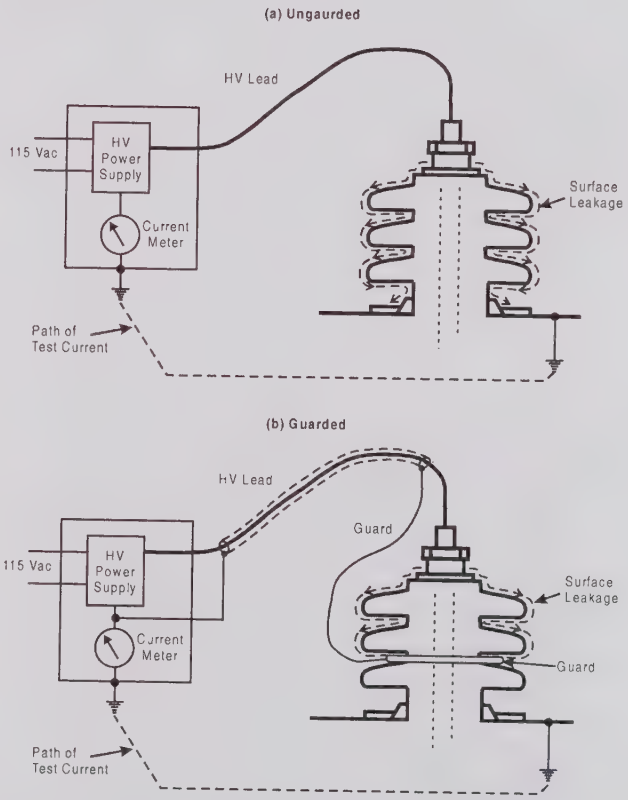

Figure 6: Unguarded and guarded test set connections

Understanding the Effects of Line Transient Surges (Noise)

Sometimes the test set readings change erratically, making it impossible to take a reading or even to average the difference between high and low swings. This is probably caused by power line transient currents. Transient currents occur because the power line does not maintain a constant voltage. The voltage variation can be due to the following:

1. Variations caused by power line voltages changing slowly over a long period. Slow voltage changes do not affect the tests discussed here because the tests are of relatively short duration.

2. Transients caused by switching surges, which are the result of switching on the high voltage side of the power distribution system. These vary in intensity: some are negligible, but others are sufficient to prevent acceptable readings.

   Strong switching surges can still be short in duration, lasting only a cycle or two. They can affect the measurement of insulation resistance because they cause the output of the high voltage test set to change in voltage. Consequently, the current you are measuring also changes.

3. On low voltage systems, transients caused by motors starting, etc. tend to be longer than switching surges, extending over tens or hundreds of cycles. They can cause unacceptable insulation measurement readings.

If the voltage goes up, the current into the UUT will increase. If the voltage goes down, some stored energy in the UUT will be discharged back into the test set. Consequently, transients can cause the output current of the test set to change in a positive or negative direction.

If a large number of transients occur, they can make it nearly impossible to measure the average current being taken by the UUT. This will make it difficult, if not impossible, to assess the quality of the insulation.

If you encounter line transients, here's what you can do about them.

Line transients often vary in intensity and are worse at some times and better at others. Try repeating the test to see if the line improves. Or you can try another line, if it is available.

You can average the swings in the output current that you read on the current meter and assume the true current should be midway between the highest and lowest reading.

For better results, connect a voltage regulator between the power outlet and the test set. This helps to limit the variations and tends to average the current swings and give a steadier indication.

NOTE: Large swings of output current may be due to line transients or caused by intermittent partial breakdowns in the UUT!

Figure 7: A 70 kV dc test set, which is available with analog or digital metering. Two other models offer test voltage up to 120 kV or 160 kV.

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4

THE PROOF TEST

The proof test is a quick and relatively inexpensive test for UUT's of any capacitance. It gives simple, go/no-go results that tell you whether your equipment is in working order at the time of the test.

- If the insulation is in good condition, the apparatus will not fail under the proof test.
- If the insulation is poor, the apparatus will break down.

When conducting a proof test, you do not:

- Measure insulation resistance
- Record any data
- Make comparisons with previous tests.

Therefore, the proof test does not give information that helps you to predict future failure of the UUT.

The instructions for performing the proof test describe the basic methods to be followed for all tests. You should be thoroughly familiar with proof test procedures before you attempt any other test methods.

How to Perform the Proof Test

1. Follow the instructions given in Section 3, "Preparing for the Test," paying special attention to the SAFETY PRECAUTIONS.

2. Connect the high-voltage test set to the UUT as described in Section 3.

3. Switch on the test set.

4. Apply a voltage higher than the normal working voltage as determined in your pre-planning procedure, making sure that the test voltage you have selected complies with the manufacturer's recommendations (see Section 3). Raise the voltage from zero to the test voltage in 30 to 60 seconds at a constant, steady rate.

   CAUTION: Increasing the voltage too quickly can generate transient voltage surges or oscillations that could cause unnecessary stress and possible breakdown of the UUT.

WARNING!

Do not touch the UUT or the connections!

5. Maintain the voltage for the pre-selected test duration, typically from 1-10 minutes as established by the manufacturer's recommendation or national standards. Monitor the output voltmeter reading. Then reduce the voltage to zero.

6. Switch off the test set.

CAUTION: Switch off the test set immediately if you have flashover. Flashover causes an overcurrent trip or a circuit breaker on the test set to open. The current meter reading will increase rapidly and then fall to zero. The voltmeter reading will also decrease to zero. Flashover tells you that an insulation breakdown has occurred.

NOTE: Some test sets are fitted with a "sample-and- hold" voltmeter circuit. In this case, the voltmeter will display the voltage at which breakdown occurred until it is manually reset.

Post Test Procedures

1. Reset the voltage test set control to zero.

2. Discharge the stored charge in the UUT through the test set to ground. Use a correctly rated resistance discharge stick or other approved discharge device, followed by grounding with a grounding stick.

> ***SAFETY NOTE***
> *Always leave the UUT grounded for 5 to 10 times as long as the test voltage was applied. The absorption current is reversible. The energy absorbed when the current is applied is stored in the dielectric. It will cause a voltage to appear across the UUT after it has been disconnected from the high voltage, even if short-circuited for a time.*
>
>
>
> ***WARNING!*** *Do not touch or change connections until the UUT voltage decays to a safe, low value.*

3. Observe the voltage decrease on the test set kilo- voltmeter until the reading is below 20 volts. To reduce the decay time, provide a parallel path to ground by using a specially designed Biddle® Discharge Stick, Catalog No. 222070-62, 222120- 62, or 222160-62.

Note: A discharge-path resistance of less than 10 megohms may cause current surges and voltage oscillations at high frequencies within the UUT. A Biddle Discharge Stick employs resistors to reduce discharge times without causing voltage oscillations.

4. When the voltage decays below 20 volts, use the direct grounding-hook connection to provide a visible, convenient, low-impedance path to the ground.

WARNING!

The direct grounding-hook is safer to use than a concealed relay inside the test set. A concealed relay malfunction could cause premature grounding. It could also fail to provide any positive connection to earth. Either of these circumstances would be a hazard to equipment and personnel. Follow the instructions in Section 8, paying careful attention to SAFETY PROCEDURES.

Figure 8: A typical discharge and grounding stick. The end hook applies a resistance to discharge the UUT, and the side hook applies a direct ground connection.

Note: The value and voltage rating of the resistor used for the discharge must be correctly rated for the capacitance and voltage of your test. Refer to manufacturer's literature for this rating.

THE CURRENT DURING DISCHARGE FLOWS IN REVERSE.
Many Biddle Test Sets have digital meters and will show the reversed polarity and magnitude. If you are using an analog meter, the magnitude of the reverse current can be read only if it has a reversing-polarity switch.

Interpreting the Results

- If the UUT withstood the voltage for the recommended time period, the insulation on the UUT is in good condition.

- If the test voltage caused flashover before the end of the time period or if the test set overcurrent circuit tripped, the insulation on the UUT is in poor condition.

If Flashover Occurred Externally:

1. Check to be sure that you applied the correct voltage for the right amount of time.

2. Follow post-test procedures to decrease voltage and ground the apparatus.

3. Clean the terminals, motor windings, high-voltage connection points and other external insulation.

4. Reposition the test leads if they were too close.

5. Try again. Watch and listen carefully.

If the Flashover Occurred Internally:

1. Check to be sure that you applied the correct voltage for the right amount of time.

2. Try to locate the problem by reviewing the instruction manual for the UUT for any help it can give.

3. Make a very careful physical examination for signs of damage. Sometimes you will have to disassemble part of the UUT. (First follow Safety Procedures.)

    - When you have located the problem, you will have to decide whether to repair the equipment or replace it.

5

THE INSULATION RESISTANCE TEST

If perfect insulation existed, there would be no flow of electrical current through the insulation to ground. But since no insulation has infinite resistance, there is always some leakage current flowing through it. While a small amount of current through good insulation is not a problem, difficulties arise when the insulation begins to deteriorate and the leakage current increases. The insulation resistance test measures the resistance of the insulation material to the flow of the leakage current, helping you to judge the condition of the insulation.

When you make this test, you can either:

- Measure the resistance of the insulation using a Megger Insulation Tester

  or

- Measure the flow of the leakage current using a test set calibrated for current. You will then have to calculate the resistance by using Ohm's Law, (see Section 2)

By performing insulation resistance tests regularly and recording the results, you can:

- Detect any gradual decrease in the insulation resistance.

- Decide whether the insulation resistance is too low for the particular apparatus that you are testing.

This gives you a means to predict future failure.

The insulation resistance test can be used on any UUT with a capacitance low enough to give a steady meter reading after the dc voltage has been applied for a reasonably short time. See Section 2, "Which Test Should I Use?," for a discussion of high and low capacitance UUT's and time-dependent currents.

How to Perform the Insulation Resistance Test

1. Follow instructions in Section 3, "Preparing for the Test," paying careful attention to the SAFETY PRECAUTIONS.

2. Measure the temperature of the UUT.

   Insulation resistance measurements are altered by changes in the temperature of the insulating material. When temperatures go up, insulation

resistance goes down. If temperatures drop, the insulation resistance will increase.

The best way to obtain consistent results is to test insulation at a standard temperature, (usually 20°C/68°F). Since this is obviously not always possible, you should correct the readings to a constant temperature. This means you will have to measure the temperature of the equipment under test. There are several ways to do this:

- If the UUT has been out of service for a considerable period of time, it will probably be close to ambient temperature and measuring the ambient temperature is fairly accurate.

- Most oil-filled apparatus have built-in thermometers to record the average oil temperature and, since the insulation will be immersed in the oil, these thermometers will give a good indication of temperature.

- In other circumstances, it may be necessary to use contact or immersion type thermometers to obtain the temperature. With motors and generators, it is usually possible to obtain the temperature of the winding either by contact or by measuring the winding resistance. If the winding resistance is known at a standard temperature, (usually from the nameplate or instruction material), any resistance variation is due to the temperature coefficient of the copper wire. This is 0.218% per degree Fahrenheit.

- In some circumstances, the only approach is to note the ambient temperature and use common sense to decide how the temperature of the apparatus varies from ambient. This is not very accurate, but it is a good deal better than having no indication of the temperature of the insulation to be tested.

3. Connect the high-voltage test set to the UUT as described in Section 3.

4. Switch on the test set.

5. Apply the test voltage, raising it from zero to the selected voltage in 30 to 60 seconds at a constant, steady rate. Insulation resistance tests are usually made at or near normal working stress, (see Section 3). Maintain the test voltage until the reading becomes steady (See Section 2, "Which Test Should I Use?" for an explanation of time-dependent currents and unsteady meter reading.)

WARNING!

Do not touch the UUT or connections.

CAUTION: Increasing the voltage too suddenly may generate transient voltage surges or oscillations that could cause unnecessary stress and possible breakdown of the UUT.

6. Measure and record the resistance, or measure and record the current and test voltage. Reduce the voltage to zero.

7. Switch off the test set.

CAUTION: Switch off the test set immediately if you have flashover. Flashover causes an overcurrent trip or a circuit breaker on the test set to open. The current meter reading will increase rapidly and then fall to zero. The voltmeter will also decrease to zero. Flashover tells you that an insulation breakdown has occurred. Check to be sure that you applied the correct voltage for the right amount of time.

Post-Test Procedures

1. Reset the voltage control to zero.

2. Discharge the stored charge in the UUT through the test set to ground. Use a correctly rated resistance discharge stick or other approved discharge device, followed by grounding with a grounding stick. (See page 4-6, Figure 8, for an illustration of a grounding stick.)

SAFETY NOTE
Always leave the UUT short-circuited for 5 to 10 times as long as the test voltage was applied. The absorption current is reversible. The energy absorbed when the current is applied is stored in the dielectric. It will cause a voltage to appear across the UUT after it has been disconnected from the high voltage, even if short-circuited for a short time.

WARNING! Do not touch or change connections until the UUT voltage decays to a safe, low value.

3. Observe the voltage decrease on the test set kilovoltmeter until the reading is below 20 volts. To reduce the decay time, provide a parallel path to the ground by using a specially designed discharge stick such as the Biddle Discharge Stick, Catalog No. 222070-62, 222120-62, or 222160-62.

NOTE: A discharge-path resistance of less than 10 megohms may cause current surges and voltage oscillations at high frequencies within the UUT. A Biddle Discharge Stick employs resistors to reduce discharge times without causing voltage oscillations.

4. When the voltage decays below 20 volts, use the direct grounding-hook connection to provide a visible, convenient, low-impedance path to the ground.

WARNING!

The direct grounding-hook is safer to use than a concealed relay inside the test set. A concealed relay malfunction could cause premature grounding. It could also fail to provide any positive connection to earth. Either of these circumstances would be a hazard to equipment and personnel. Follow the instructions in Section 8, paying special attention to all Safety Precautions.

THE CURRENT DURING DISCHARGE FLOWS IN REVERSE

Many Biddle Test Sets have digital meters and will show the reversed polarity and magnitude. If you are using an analog meter, the magnitude of the reverse current can be read only if it has a reversing-polarity switch.

Correcting the Measurement to Allow for Temperature Variations

If the temperature of the UUT was higher or lower than 20°C, (68°F), you can make a rough correction to 20°C by:

- Halving the resistance measurement you have taken for every 10°C above the base temperature of 20°C.
- Doubling the resistance measurement for every 10°C below 20°C.

This rough calculation is not accurate. Each type of insulation material reacts differently to temperature changes because its temperature coefficient (% of change of resistance per degree) is different.

- For major apparatus it may be possible to find out the temperature coefficient from the manufacturer.

If the temperature coefficient is not available, it may be worthwhile to establish it yourself. See Appendix A for instructions.

Using Ohm's Law to Calculate Resistance Measurement

If you used a test set that measures current, refer to Section 2 for instructions on calculating the insulating resistance using Ohm's Law.

Interpreting the Data

If the insulation resistance reading was high and if it increased or remained steady during the test, the insulation is good. Current decreases as insulation resistance increases.

If the insulation resistance reading decreased during the test, the insulation of the UUT is probably wet or otherwise in bad condition.

If the final value is low (or the current is high), the insulation of the UUT is poor.

What do we Mean When we Say the Insulation Resistance Reading is High or Low?

It depends on the UUT. In some circumstances a reading of 1 megohm would be satisfactory. In other cases a reading of anything less than 1000 megohms might be unsatisfactory.

To find the correct value of insulation resistance for the UTT, you must rely on the manufacturer's information, on standards or on your experience with similar apparatus.

For three-phase apparatus it is very useful to compare the three phases. They should all be quite similar if they are in working condition, or if some problem (moisture, contamination, etc.) is affecting

them all. In most cases deterioration will produce worse results in one phase than the other two.

Here are some "rule of thumb" figures to give you an idea of what to expect for 15kV cables at 68°F in typical medium-length routes.

Cross-linked polyethylene (XLPE) cable has the lowest leakage current - usually less than 10 microamperes, (1500 Megohms).

Ethylene Propylene Rubber (EPR) and natural rubber cables usually have leakage currents of less than 20 microamperes, (750 Megohms).

Oil-impregnated lead covered (PILC) cables usually have leakage currents of less than 50 microamperes, (300 Megohms).

Cable splices and terminators will increase the leakage current, because they provide additional leakage paths in parallel with the UUT.

Oil-filled high-voltage equipment has widely varying leakage currents depending on the volume and the quality of the oil and solid materials that are used.

Another useful concept for judging resistance readings on cables or bus structures is that of megohms per foot or megohms per microfarad of UUT capacitance. Since the insulation resistance is directly related to the length of the cable, it is possible to state a value per unit length and then relate the result of a known length to the unit value. For example, doubling the length of a cable will halve the insulation resistance except for the effect

of terminations. The unit capacitance is also related to length and can be used in a similar way.

Action Needed If Insulation Resistance Is Low

After following post-test procedures to decrease voltage and ground the apparatus:

- Clean the insulation. Apply gentle heat to dry it out.
- Retest.

If the insulation resistance is still low, you must decide to repair or replace the insulation or the equipment. If necessary, consult the manufacturer or engineering support services for guidance.

Maintaining Records

The best method of interpreting test results is to compare the present reading with a history of readings going back to the acceptance of the unit when new. For optimum results, tests should be made at regular intervals with a careful note of the circum- stances and correction for temperature.

If you have earlier records, has the insulation resistance on the present test decreased markedly since the last test? If so, the insulation requires maintenance, cleaning and drying or replacement.

By comparing the data with records from previous tests, you will be able to detect a downward trend in the insulation resistance, even though it may still be good enough to allow the equipment to continue in service while you make plans to repair or replace the equipment.

6

THE POLARIZATION INDEX TEST

When testing high capacitance equipment (large motors, generators or apparatus with complex insulation systems), you will not be able to get a steady insulation resistance reading until the time-dependent currents have almost died down. This means that an insulation resistance test as described in Section V is unsuitable for high capacitance UUT'S. (See Section 2, "Which Test Should I Use?" for a discussion of high capacitance apparatus and time-dependent currents.)

One way around the problem of time-dependent currents is to use a polarization index test, which measures the ratio between insulation resistance readings taken at one minute and ten minutes after the application of the voltage. The trend indicated by this ratio will allow you to judge the rate at which the capacitance and absorption currents are disappearing. After taking into account variations in different types of insulation, you will be able to evaluate the condition of the insulation.

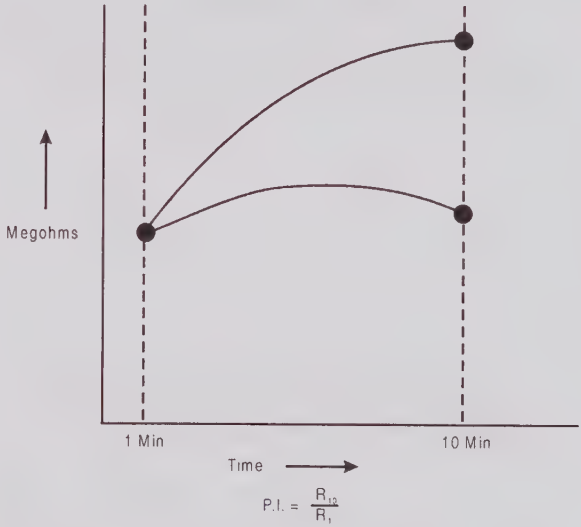

Figure 9: The Polarization Index (PI) test.

There are several advantages to a polarization index test:

- You do not have to wait for a steady meter reading, because you are looking for a trend rather than a single reading.
- You do not have to adjust the measurement to allow for variations in the temperature of the UUT as you must when you perform a simple insulation resistance test.
- You can use either a medium-voltage test set such as the Megger® Insulation Tester or a

high- voltage test set, to suit your convenience or as voltage ratings demand.

- The polarization index will tell you if the insulation is damp or dirty. Moisture and dirt have a flattening effect on the PI curve. For this reason we especially recommend this test if the UUT is old.

How to Perform the Polarization Index Test

1. Follow the instructions given in Section 3, "Preparing for the Test," paying careful attention to SAFETY PRECAUTIONS.

2. Have available a stopwatch or timer.

3. Use a test set calibrated for resistance measurement.

4. Connect the high-voltage test set to the UUT as described in Section 3.

5. Switch on the test set.

6. Apply the test voltage as determined in your pre-planning procedures (see Section 3). Raise the voltage from zero to the selected test voltage in 30 to 60 seconds at a constant, steady rate. When you reach full voltage, start timing the test.

WARNING!

Do not touch the UUT or connections.

CAUTION: Increasing the voltage too suddenly may generate transient voltage surges or oscillations that could cause unnecessary stress and possible breakdown of the UUT.

7. One minute after you apply the voltage, measure and record the resistance.

8. Ten minutes after you apply the voltage, measure and record the resistance again. (This means a nine- minute interval between measurements.) Reduce the voltage to zero.

9. Switch off the test set.

CAUTION: Switch off the test set immediately if you have flashover. Flashover causes an overcurrent trip or a circuit breaker on the test set to open. The current meter reading will increase rapidly and then fall to zero. The voltmeter will also decrease to zero. Flashover tells you that an insulation breakdown has occurred. Check to be sure that you applied the correct voltage for the right amount of time.

NOTE: Some test sets are fitted with a "sample-and- hold" voltmeter circuit. In this case, the voltmeter will display the voltage at which breakdown occurred until it is manually reset.

Post-Test Procedures

1. Reset the voltage control to zero.

2. Discharge the stored charge in the UUT through the test set to ground. Use a correctly rated resistance discharge stick or other approved discharge device followed by grounding with a grounding stick. (See page 4-6, Figure 8, for illustration of a grounding stick.)

> ***SAFETY NOTE***
> *Always leave the UUT short-circuited for 5 to 10 times as long as the test voltage was applied. The absorption current is reversible. The energy absorbed when the current is applied is stored in the dielectric. It will cause a voltage to appear across the UUT after it has been disconnected from the high voltage, even if short-circuited for a short time. WARNING: Do not touch or change connections until the UUT voltage decays to a safe, low value.*

3. Observe the voltage decrease on the test set kilo voltmeter until the reading is below 20 volts. To reduce the decay time, provide a parallel path to the ground by using a Biddle Discharge Stick, Catalog No. 222070-62, 222120-62, or 222160-62.

NOTE: A discharge-path resistance of less than 10 megohms may cause current surges and voltage oscillations at high frequencies within the UUT. A Biddle Discharge Stick employs resistors to

reduce discharge times without causing voltage oscillations.

4. When the voltage decays below 20 volts, use the direct grounding-hook connection to provide a visible, convenient, low-impedance path to the ground.

WARNING!

The direct grounding-hook is safer to use than a concealed relay inside the test set. A concealed relay malfunction could cause premature grounding. It could also fail to provide any positive connection to earth. Either of these circumstances would be a hazard to equipment and personnel. Follow the instructions in Section 8, paying special attention to all Safety Precautions.

THE CURRENT DURING DISCHARGE FLOWS IN REVERSE

Many Biddle Dielectric Test Sets have digital meters and will show the reversed polarity and magnitude. If you are using an analog meter, the magnitude of the reverse current can be read only if it has a reversing-polarity switch.

Interpreting the Data

- Divide the first reading taken at one minute into the second reading taken at ten minutes. This will give you the ratio between the two. The ratio is the polarization index. For example, if the first reading is 500 Megohms and the second reading is 1000 Megohms, divide 1000/500. The polarization index is 2.0.

- Polarization index values of less than 1.0 are always an immediate cause for concern.

- Values of 1.0 are satisfactory for very low capacitance equipment.

- Values of greater than 1.0 are to be expected for high capacitance UUT's with good insulation.

What is a Good Polarization Index?

There are no hard and fast rules for a "good" polarization index. For this reason it is important to maintain good records from past tests so that you have a standard of comparison.

Low values can be expected when you are testing:

- Short lengths of shielded cables

- Small rotating motor windings

- Bus systems.

In these cases the maximum value of insulation resistance may be reached within 2 or 3 minutes. When this occurs, low values of polarization index are usual and do not indicate that the insulation is in poor condition.

If the insulation resistance increased rapidly during the initial 1 to 2 minutes, the condition of the insulation is probably satisfactory.

The index ratio will vary with different types of insulation. Here are some "Rule of Thumb" Values:

- Shielded power cables and rotating machine windings with a capacity greater than 0.02 Microfarads typically have polarization index values of 1.5 or higher.
- Older generating units with stator coils built up of many layers of flexible paper tape can have polarization index values of 2.5 or higher.
- Newer generating units with epoxy systems made by vacuum processing of coils usually have polarization index values of 2.0 or less.
- Oil-filled apparatus such as transformers usually have polarization index values of 1.1 to 1.3.
- Surface conductive dirt and surface moisture films are a frequent cause of low polarization index readings.

- In general, the higher the polarization index for large capacitance UUT'S, the better is the insulation.

Action Needed if Polarization Index Values are Unsatisfactory

If the value you obtained is unsatisfactory, the problem may be caused by wet and/or dirty insulation surfaces. Do not make further high voltage tests until you have corrected this condition, because further damage may occur.

After following post-test procedures to decrease voltage and ground the apparatus:

1. Clean and dry the surfaces of the insulation.

2. Inspect for conductive surface tracking.

3. Test again.

If the polarization index is still low, an internal problem with the insulation is indicated. Probably there is moisture in the bulk of the insulation. In rare cases there may be some other kind of deterioration. Inspect the insulation and locate the problem.

If necessary, you may have to decide whether to repair or replace the equipment. Consult the manufacturer or engineering services for advice.

7

THE STEP-VOLTAGE TEST

The best way to test high capacitance UUT's is to use a step-voltage test which provides more information about the condition of insulation than any other test.

This section tells you how to:

- Measure the current at several different levels of voltage.
- Plot the readings on a graph to establish a trend or curve.

Added to other relevant information, the curve will

- Help you to predict future problems.

- Warn you of the probability of imminent failure of the insulation without causing UUT breakdown.

- Allow you to continue to use the apparatus in service while arrangements are made to replace it.

When you make a step-voltage test, you do not have to:

- Wait for a steady meter reading, because you are looking for a trend not a single reading.

- Adjust the measurements to allow for temperature variations.

Using the Step-Voltage Test to Establish a Record

If possible:

- Perform the step-voltage test for the first time when the equipment is new.

If this is not possible:

- Try to perform the test when the equipment is clean and dry.

A careful, accurate record of the data from this first test will give you a good basis on which to judge the result of future tests.

Each subsequent time you test:

- Use the same voltages and time intervals.
- Record the results on the same kind of graph paper.

This will make it easier to compare data and detect any changes in insulation condition.

Repeating the step-voltage test regularly for routine maintenance at six-month intervals may be appropriate the apparatus must remain in operation at all times. Testing at one- to four-year intervals may be sufficient for other applications.

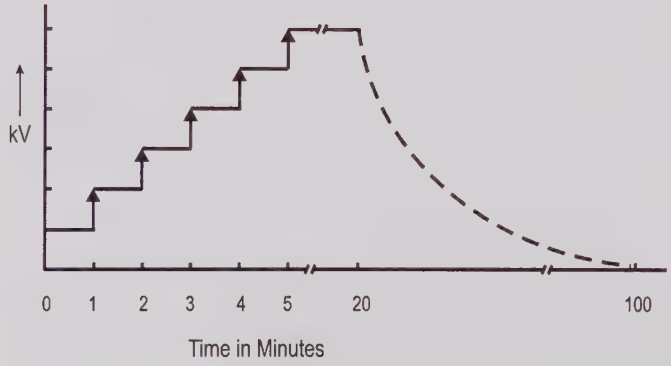

Figure 10: The Step-Voltage test.

How to Perform the Step-Voltage Test

1. Follow instructions in Section 3, "Preparing for the Test," paying special attention to the safety precautions.

2. Use a test set with current metering.

3. Pre-plan the test so that you know the voltages, test levels and number of steps you are going to use. The voltage steps should be the maximum voltage to be applied divided by the number of Steps.

- For example: If the maximum voltage is 10,000 volts and five steps are used, each step should be 2000 volts.

- The time interval used will depend on the capacitance and insulation system of the UUT. It is best to choose an interval that gives a changing value of insulation resistance for each step. If the interval is too long, the last steps will be constant. Experimentation with a medium-voltage test will help to establish a suitable time interval. One-minute steps are typical for a wide range of UUTS.

4. Have available a stopwatch or timer.

5. Prepare a sheet of graph paper so that you can plot the results after the test is complete. If you use Biddle Kilovolt-Megohm Paper, Catalog No. 220000, insulation resistance values are automatically made available even though you plot data in units of current.

6. Record on the graph paper the dc equivalent voltage to ground of the UUT. See Section 3, "Preparing for the Test," for information on voltage ratings and test voltages.

7. Record the maximum voltage selected for the test so that you have a guideline as the voltage is increased.

8. Connect the high-voltage test set to the UUT as described in Section 3.

9. Switch on the test set.

10. Raise the output voltage to the first selected step level with a single constant motion. Avoid slight tweaking adjustments of the step voltage settings since they interfere with the exponential change of current and distort the test data. It's better to have a slight error in the voltage setting than to make a small adjustment after the single constant motion for the step is complete.

WARNING!

Do not touch the UUT or the connections.

CAUTION: Steady or irregular increases of current in the interval after raising the voltage may be the first sign of impending insulation breakdown. Terminate the test at this point before complete breakdown occurs. Consider the possibility that the UUT may be returned to service on a temporary basis until repair or replacement is made.

11. Keep the test voltage constant during the selected time interval.

12. Record the current reading at one minute.

13. Immediately raise the voltage to the next step level following the same precautions mentioned in the first step. To avoid incorrect results, the meter reading must be made after the same time interval for each step.

14. Continue applying the voltage to the UUT in two, three or four successive steps until the preselected maximum voltage is achieved. Record the result at each step. Reduce the voltage to zero.

15. Switch off the test set.

CAUTION: Switch off the test set immediately if you have flashover. Flashover causes an overcurrent trip or a circuit breaker on the test set to open. The current meter reading will increase rapidly and then fall to zero. The voltmeter will also decrease to zero. Flashover tells you that an insulation breakdown has occurred. Check to be sure that you applied the correct voltage for the right amount of time.

16. Plot the points representing the output voltage and meter readings on log-log paper. (See Appendix B). Note: During the time interval the current should decrease due to reduction in capacitive charging and absorption currents. These currents are highest immediately following a voltage step.

17. Draw a best-fit curve between the points on the graph paper.

Post Test Procedures

1. Reset the voltage control to zero.
2. Discharge the stored charge in the UUT through the test set to ground. Use a correctly rated resistance discharge stick or other approved discharge device, followed by grounding with a grounding stick. (See page 4-6 for illustration of a Biddle Discharge Stick (Figure 8.)

SAFETY NOTE
Always leave the UUT grounded for 5 to 10 times as long as the test voltage was applied. The absorption current is reversible. The energy absorbed when the current is applied is stored in the dielectric. It will cause a voltage to appear across the UUT after it has been disconnected from the high voltage, even if short-circuited for a short time.

WARNING! *Do not touch or change connections until the UUT voltage decays to a safe low value.*

Observe the voltage decrease on the test set kilovoltmeter until the reading is below 20 volts. To reduce the decay time, provide a parallel path to the ground by using a specially designed Biddle, Discharge Stick, Catalog No. 222070-62, 222120-62 or 222160-62.

NOTE: A discharge-path resistance of less than 10 megohms may cause current surges and voltage oscillations at high frequencies within the UUT. A Biddle Discharge Stick employs resistors to reduce discharge times without causing voltage oscillations.

3. When the voltage decays below 20 volts, use the direct grounding-hook connection to provide a visible, convenient, low-impedance path to the ground.

WARNING!

The direct grounding-hook is safer to use than a concealed relay inside the test set. A concealed relay malfunction could cause premature grounding. It could also fail to provide any positive connection to earth. Either of these circumstances would be a hazard to equipment and personnel. Follow the instructions in Section 8, paying special attention to all Safety Precautions.

THE CURRENT DURING DISCHARGE FLOWS IN REVERSE

Many Biddle Dielectric Test Sets have digital meters and will show the reversed polarity and magnitude. If you are using an analog meter, the magnitude of the reverse current can be read only if it has a reversing-polarity switch.

Interpreting the Data

Look at the curve you have drawn on the graph paper. If you used Biddle Kilovolt-Megohm Paper, Catalog No. 220000, insulation resistance values are automatically made available even though you plotted data in units of current.

If the measured insulation resistance values increased as the voltage was raised and continued to rise as you exceeded the operating voltage:

- The insulation is probably very good. Increasing insulation resistance shows that the leakage currents are very low compared to the normal charging current values. This is the preferred condition when using short test time intervals.

If the insulation resistance remained nearly constant until test voltages well above operating voltage were reached:

- The insulation is probably good. The higher the voltage that is reached before a decrease in insulation resistance occurs, the better the insulation is likely to be.

If the insulation resistance remained nearly constant but decreased before reaching the value of the operating voltages:

- After following post test procedures to decrease voltage and ground the apparatus, clean and dry the surfaces of the insulation so that no leakage current comes from the terminations.

Apply a guard terminal if appropriate (see Section 3).

- Make sure the clearance between high voltage and grounded surfaces is not too close and therefore causing corona. See Appendix C for a discussion of corona.

- Repeat the test.

If the insulation resistance still decreases, incipient breakdown is indicated. Investigation of the problem and repairs or replacement are required at this point.

If the resistance decreased with a constant down slope as the voltage increased:

- The insulation is probably damp with dirty surfaces.

After following post-test procedures to decrease voltage and ground the apparatus:

- Clean the insulation. Apply gentle heat to dry it out.

- Repeat the test.

- If the condition persists after cleaning and drying, some other problem exists. This will require investigation and possibly repairs or replacement.

For a really accurate diagnosis of the condition of the insulation, you should also consider other

relevant information. This may include the following:

- Previous history of the apparatus.
- Results of a careful visual inspection.
- Comparison with other similar equipment.
- Manufacturer's recommendations.
- Other specifications that may be relevant, see Appendix D.

If, having considered all available information, you decide that the insulation is in fair condition with some deterioration since the previous test, you should either:

- Remove the equipment from service and decide whether to repair or replace it.

Or:

- Allow the equipment to continue in service, while arrangements are made to repair or replace it.

If you decide that the insulation is in poor condition, you should:

- Remove the equipment from service and decide whether to repair or replace it.

Consult the manufacturer or engineering support services, if necessary.

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APPENDIX A – ESTABLISHING TEMPERATURE COEFFICIENTS

If the temperature coefficient for the equipment under test is not available from the manufacturer, it may be worthwhile to establish it yourself. If possible, make the following calculations when the apparatus is new. If this is not possible, at least try to make them when the apparatus is clean and dry.

- Follow the instructions for performing an insulation resistance test. See Section 5.
- Measure the insulation resistance at different times when the temperature is different, (ideally at or near 10°C/56°F, 20°C/68°F, 30°C/86°F, and 40°C/104°F).
- Plot these values on semi-log paper, plotting temperature along the horizontal linear scale and resistance along the vertical log scale.

- Draw a best-fit line through the plotted points.
- Select a base temperature (e.g. 20°C) and read the resistance plotted at that temperature.
- Determine the correction factor at any temperature by dividing the resistance reading at that temperature into the resistance reading at the base temperature, as follows:

$$\text{N correction factor} = \frac{\text{Resistance at Base Temperature}}{\text{Resistance at Actual Temperature}}$$

To correct a resistance measured at any temperature to its equivalent resistance at the base temperature, multiply the measured resistance by the correction factor for that temperature.

For information on temperature adjustments in insulation resistance testing, see Section 5.

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APPENDIX B – DOCUMENTING YOUR RESULTS

It is also worth considering setting up a database, either in a personal or mainframe computer. This will allow you to perform calculations such as the adjustment of results to a standard temperature, as well as providing means of storing data and printing reports.

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APPENDIX C - CORONA

You can often see (and hear) corona hissing and glowing around high-voltage cable and insulation during wet weather. Corona is a partial discharge in a high-voltage field that does not bridge the gap between the high voltage and ground. Partial discharges are different from breakdown flashovers or arcs. Partial discharges can occur in solid or liquid insulation, but when we talk about corona, we mean partial discharges in air.

Corona usually occurs at some point where discharge occurs due to the breakdown of a small area of the insulation. This breakdown requires some power to be drawn from the supply

The extra current drawn from the supply has two effects on insulation resistance measurements. First, the extra current is recorded by the output meter and consequently gives a false high reading of current, (or low reading of insulation resistance).

Secondly, the current is pulsing, which tends to cause the meter to read erratically, thus making it difficult to obtain a reading.

In practice, corona usually occurs at sharp paints and edges on the high-voltage conductor. One cure is to apply some semi-conducting putty over the sharp parts. Almost any putty-like material such as duct seal will work. It increases the effective radius of the part without greatly reducing the flashover voltage.

Another approach is to tie a plastic bag over the part. This fills up with ionized particles generated by the corona. Since the particles are conductive, they also increase the radius of the part by air currents and often blow the bag up like a balloon. (See Figure 4, page 3-10)

WARNING!

If the plastic bag blows up like a balloon, it has become charged and must be discharged to ground with a stick before you touch it.

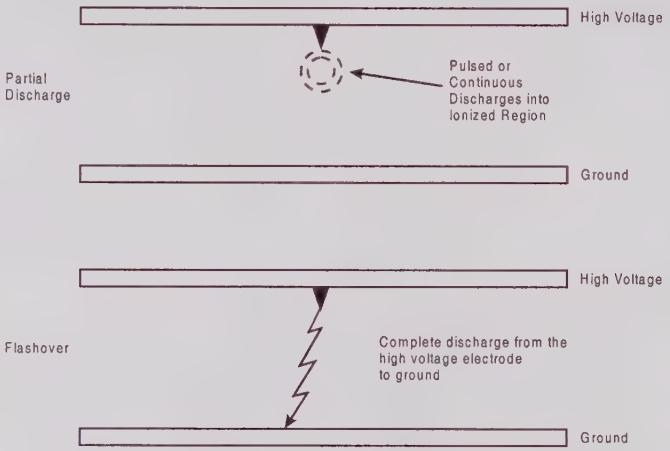

Figure 11: Partial discharge within an insulator vs. a complete breakdown and flashover

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APPENDIX D - REFERENCES

The following publications were prepared by engineering committees concerned with different high- voltage apparatus used in electrical power distribution and utilization systems. Publications are obtained from sources listed, and usually a nominal charge is made for them.

POWER CABLES

IEEE 400 — Guide for Making High Direct Voltage Tests on Power Cable Systems in the Field

Includes values of test voltages related to system voltages and test methods. Also a short summary of evaluation of test results.

NEMA-ICEA Pub. WC3 — Rubber Insulated Cable

Covers all types of mechanical and electrical specifications for manufacturing, testing and

purchase of wire and cable. Includes DC test voltage values after installation.

NEMA-ICEA Publ. WC5 — Thermoplastic Cable

Covers all types of mechanical and electrical specifications for manufacturing, testing and purchase of wire and cable. Includes test voltage values after installation.

NEMA-ICEA Pub. WC7 — Cross Linked Thermosetting Polyethylene Wire and Cable

Covers all types of mechanical and electrical specifications for manufacturing, testing and purchase of wire and cable. Includes test voltage values after installation.

REA Test Standards for URD Cable

Cable installation and testing information supplied by cable suppliers. Provides installation test specifications to meet the supplier's warranty coverage.

ROTATING MACHINES

IEEE 95 — Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage

Covers dc test methods and dc test voltages on large generators and motors.

IEEE 432 — Guide for Insulation Maintenance for Rotating Electrical Machinery

Covers dc test methods and dc test voltages on small generators and motors.

IEEE 56 — Guide for Insulation Maintenance for Large AC Rotation Machinery

Covers ac and dc tests on insulating systems. No test voltage values are included.

IEEE 43 — Recommended Practice for Testing Insulation Resistance of Rotating Machinery

Covers low voltage testing on insulating systems. Lists numerical values for Polarization Index (PI) for one type of insulating material.

IEEE 62 — Recommended Guide for Making Dielectric Measurements in the Field

Covers ac and dc tests on all types of electrical apparatus. High voltage proof tests and step-voltage tests are included. No test voltage levels given.

AC SWITCHGEAR

ANSI C37.20 — Switchgear Assemblies

Covers ac and dc tests on electrical switchgear. Ac tests are preferred, but test levels for dc are included. Dc tests are Proof (Withstand) tests only.

TERMINATIONS AND BUSHINGS

IEEE 48 — Standard Test Procedures and Requirements for HV AC Cable Terminations

Covers dc Proof (Withstand) tests only. Lists the test voltage levels for ac service voltages.

INDUSTRIAL PLANT ELECTRICAL EQUIPMENT MAINTENANCE

NFPA 70-B — Recommended Practice for Electrical Equipment Maintenance

Covers ac and dc tests useful in general maintenance of electrical equipment used in a small industrial plant.

SAFETY

IEEE 510-1983 — Recommended Practices for Safety in High Voltage and High Power Testing

SOURCES FOR REFERENCED PUBLICATIONS

IEEE — Institute of Electrical & Electronic Engineers
345 East 47th Street
New York, NY 10017

NEMA — National Electrical Manufacturers Association
2101 L Street, NW
Washington, DC 20037

NFPA — National Fire Protection Association
Batterymarch Park
Quincy, MA 02269

ANSI — American National Standards Institute
1430 Broadway
New York, NY 10018

REA — Rural Electrification Administration
US Department of Agriculture
Washington, DC 20250 58

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APPENDIX E – TESTING EXTRUDED DIELECTRIC CABLES

Some believe that merely exposing service-aged XLPE cable to high voltage dc is sufficient to create additional degradation within the insulation material. Under specific conditions, performing the test could worsen a defect that would then escalate into a fault after the cable is returned to service.

During a high-voltage dc test, a hard discharge or flashover may occur. It may be due to a cable failure, an arc-over at terminations or a hard ground at the end of the test. The hard discharge or flashover results in a shock wave that reflects back and forth on the cable. The first reflection from an open circuit termination is equal and opposite in polarity to the applied dc test voltage. The result is that a hard discharge or flashover during high voltage dc testing could further degrade service-age XLPE cables containing localized weak spots.

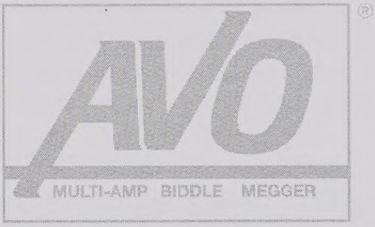
Another possible cause of cable degradation is the development of space charges that take a very long time to dissipate. The space charges occur around minor defects during testing. If the discharge time is not sufficient to dissipate the accumulated space charge, the cable will be subjected to a localized stress at the point of the defect when re-energized at the ac voltage. The space charge is a fixed polarity. The peak voltage of the ac sine wave applies stress to the area of the defect each time the sine wave reverses polarity until the space charge dissipates.

Laboratory testing indicates that if a high voltage dc test is performed without a hard discharge or flashover occurring during the test and if there is sufficient discharge time at the end of the test, no damage has been caused to the cable.

Summing up:

- Acceptance or installation testing on XLPE cables using high-voltage dc is still valid and since no treeing has developed in the new cable, no damage is done.
- Acceptance testing on XLPE cables at commonly recommended voltage levels is likely not a test of the cable quality itself but only a test for gross installation damage and of accessories.
- Maintenance testing on service-aged XLPE cable may not provide a reliable indication of cable condition because of space charges built up at defects during the test.
- Maintenance testing on service-aged XLPE cable may cause cable degradation if a flashover occurs during testing or if proper discharge procedures are not observed.

NOTES



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